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Environmental Health Center
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INVESTIGATION OF A PROPOSED RECIRCULATION SYSTEM FOR TOILET WASTES

(*)

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FOREWORD

Aerobic methods have long been used for treatment of municipal sewage. Based on information presently available, there is no reason to believe that a method which can be used to treat the wastes of millions of people cannot be adapted to individual households through the application of proper design factors. Aerobic processes making use of activated sludge have been studied by a multitude of investigators so that a basis for the transition from very large to very small plants is contained in the literature.

Continuous recirculation of aerated waste in a system from which no effluent is discharged, at least to these authors, is a new and novel idea. After a series of investigations at Purdue University, Bloodgood[2] stated that:

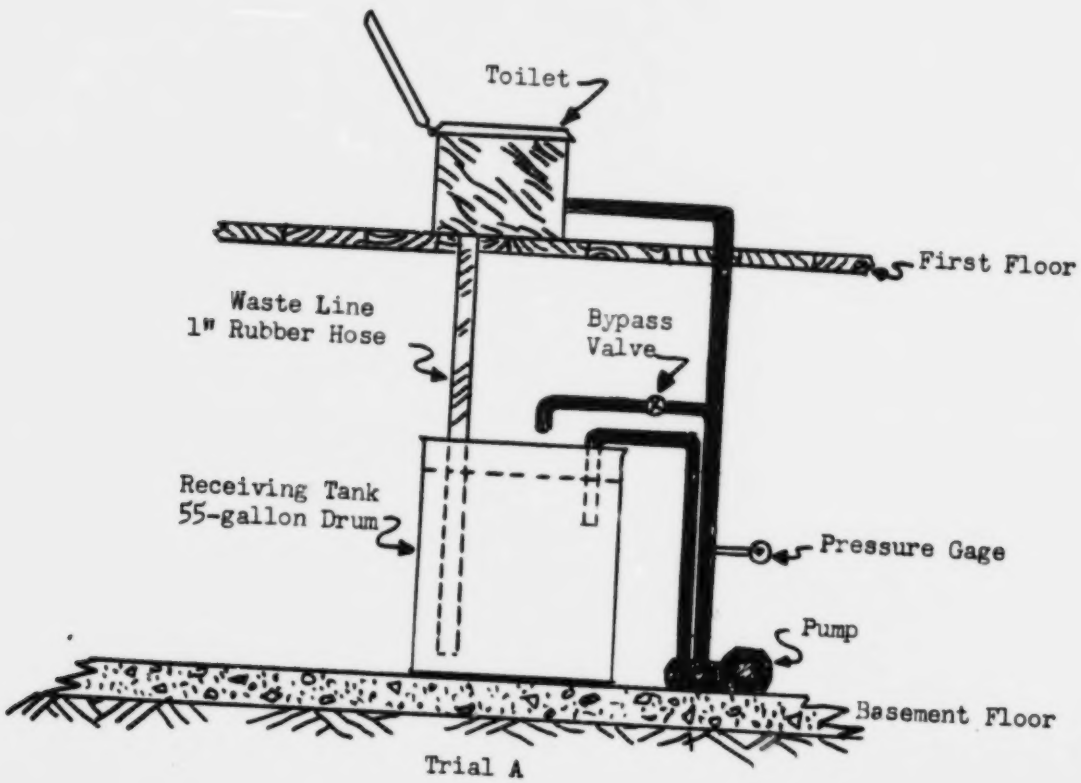
> "It was concluded that a small activated sludge plant for an individual home can be made to operate continuously and satisfactorily for over a year without the removal of any solids. It was further concluded that it is quite essential in some manner to grind all material going to the aeration unit. The 227 gallon tank used for the tests is believed to be sufficiently large to handle the sewage from three people. Recirculation of water for toilet flushing is indicated to be possible."

Investigations described in our report were limited to the study of a specific system which had been proposed for the treatment of toilet waste, and to one modification of that system. Therefore, the results obtained and the conclusions made are not necessarily indicative of the results which might be obtained with other arrangements making use of aerobic principles.

Trial A

Continuous Recirculation of Waste Through Toilet

Two trials of a proposed system for the disposal of toilet-waste were made. The system investigated in the first trial consisted of three functional units: a grinder-type toilet, a receiving tank and a small pump. The hydraulically driven grinder was located below the bowl in the base of the toilet. The pump, operating continously, recirculated the tank contents through the toilet, furnishing power to drive the grinder, and liquid to flush the toilet. Solid particles deposited in the toilet bowl were flushed into the grinder where they were finely ground and carried in the liquid by gravity flow from the toilet to the receiving tank on the floor below. No effluent was discharged from the system.



Trial A

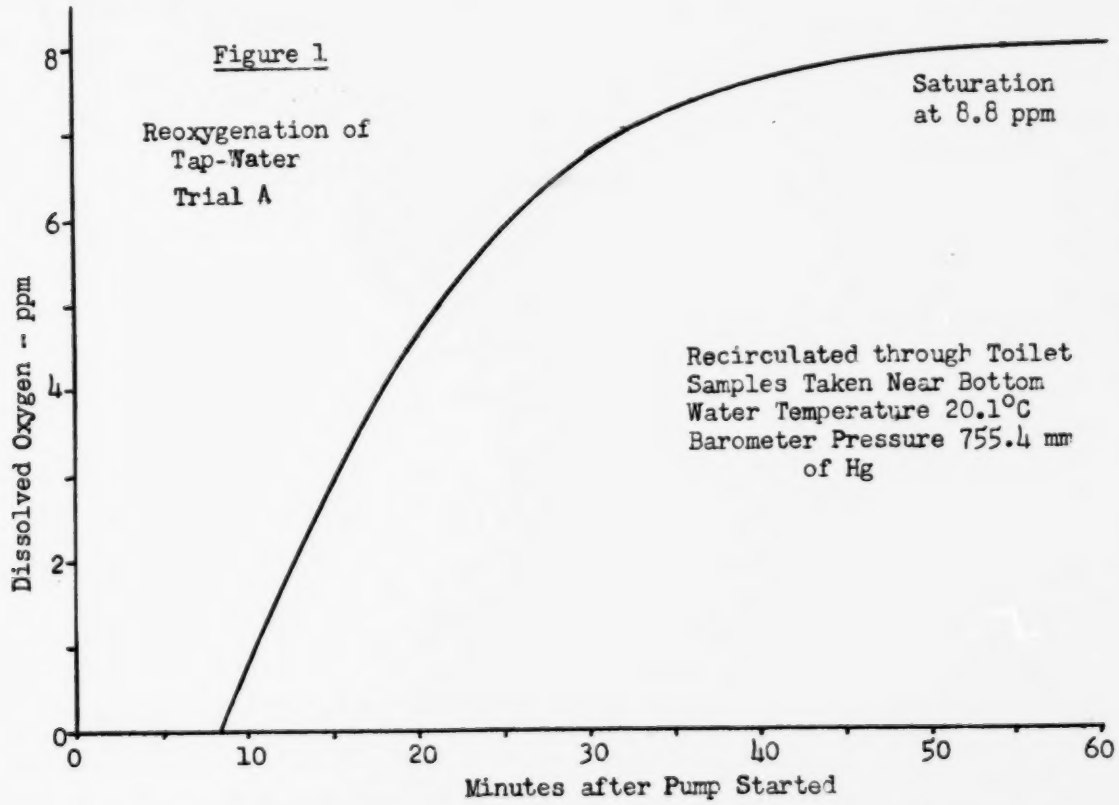
The system described above was installed at the Environmental Health Center on March 31, 1952. The grinder toilet was used to replace one of the conventional toilets in the men's rest room. Waste was conducted from the toilet by a one-inch rubber hose to a fifty-five gallon drum on the next floor below. As the pump capacity was greater than that required, a fraction of the flow was diverted through the bypass arrangement as shown in the accompanying sketch. The volume of liquor bypassed could be adjusted by manipulating a valve, thus permitting the delivery of the proper volume under the proper pressure at the toilet. The bypassed liquor was discharged above the liquid level in the receiving tank.

Using tap water, various rates of flow through the toilet were measured by collecting and weighing the discharge from the rubber hose during a given interval of time. It was found that flows greater than 2.75 gallons per minute produced an objectionable spray, while lower flows failed to produce the desired flushing action; therefore, all subsequent investigations were conducted at a flow rate of 2.75 gallons per minute. This rate was obtained by adjusting the bypass valve to give a pressure gage reading of 22 psi at the pump.

In this system there was opportunity for aeration to occur at five different points. Flushing liquid swirled through the bowl in a spiral motion before dropping through an opening onto the grinder. The thin sheet of liquid flowing in a turbulent manner around the inside of the toilet bowl presented an excellent opportunity for aeration. As the liquid passed over the grinder it was broken into fine droplets, permitting further aeration. In this same process excess air was entrained. The returning liquor was discharged to the drum near the bottom where the excess air escaped and bubbled up through the liquid. Aeration also occurred at the surface of the drum which was open

to the atmosphere, and at the point where the bypass line discharged above the tank surface.

Before the toilet was used investigations were made to determine the efficacy of the system as an aerator. Reaeration of tap water was measured using a method similar to that employed by Kessener and Ribbius[1]. With the pump stopped and forty-four gallons of water in the drum, a dissolved oxygen determination was made. A quantity of NaOH and $FeSO_4 \cdot 7H_2O$, calculated to consume all of the dissolved oxygen, was then added. Excess NaOH was added in order to keep the pH between 9.0 and 11.0 during the reaction. When the dissolved oxygen was entirely depleted, the pump was started, and determinations were made at regular intervals to determine the reoxygenation rate of the water with time. Samples for D.O. were siphoned from the bottom of the receiving tank. These results are plotted on Figure 1.



Referring to Figure 1, it is seen that approximately two minutes were required to raise the D.O. from 1 to 2 ppm. At this rate, the grinder type toilet would supply* $.166(\frac{60}{2.0})\ 24 = 119.5$ grams of oxygen to tap water every 24 hours. Rates of reoxygenation at various oxygen deficiencies are given in Table I.

TABLE I
Reoxygenation of Tap Water
(at 20°C)

Dissolved Oxygen Content ppm	Dissolved Oxygen Deficiency* ppm	Minutes Required to Increase D.O. one ppm	Grams O_2 Supplied per 24 hrs.
6.8	2	10.5	23.6
5.8	3	5.8	42.9
4.8	4	4.4	55.7
3.8	5	3.7	66.5
2.8	6	2.9	84.7
1.8	7	2.3	107.2
.8	8	1.7	144.7

*Oxygen saturation value minus oxygen content.

The toilet was put into use on April 8, 1952. Table II shows the daily usage and the amount of toilet paper consumed each week. Dissolved oxygen was determined each morning and night on samples obtained near the bottom of the receiving tank. These values are also shown in Table II.

* .166 = 166,000 grams H_2O x 1 ppm

TABLE II

Daily Record of Use and D.O.

Date	Type of Use		Toilet Paper	Dissolved Oxygen, ppm	
	Feces	Urine		Morning	Night
April 8, 1952	2	15		9.9	6.9
9	4	17		2.9	2.3
10	4	16		1.7	0.0
11	3	6		0.0	0.0
Weekly Total	13	54	55 grams		
April 14, 1952	2	17		2.7	0.7
15	3	15		1.6	1.1
16	4	14		2.4	2.1
17	3	17		2.7	0.6
18	4	10		1.5	2.6
Weekly Total	16	73	87 grams		

Once each week a sample of the tank liquor was analyzed for total, total volatile, suspended and suspended volatile solids and for B.O.D. Samples for these determinations were taken from the drum at mid-depth. These results are listed in Table No. III.

TABLE III

Weekly Solids and B.O.D. ppm

Week	Sampling Date	Solids				5 day B.O.D.
		T.S.	T.V.S.	S.S.	S.V.S.	
1	April 10, 1952	1812	1473	477	423	137
2	April 18, 1952	5548	4626	3361	2511	153

Persons using the toilet or working near the receiving drum were asked to make a record of any nuisance which developed. Following is a partial log of those observations:

Date	Remarks
4-8-52	Operation began
4-10-52	Unsightly foam and odor in tank and toilet bowl - toilet cleaned.
4-10-52	Dark brown gelatinous ring around toilet at waterline--offensive odor at toilet. Brown scum on tank--some odor—contents warm--spraying at toilet.
4-11-52	Toilet was not used during Easter weekend.
4-14-52	Strong odor and much foam at bowl--liquid, dark brown--misty spray at bowl.
4-15-52	Foam on drum - complaint of a strong sickly fishlike odor all day at toilet.
4-16-52	Foam - odor at toilet - scum on toilet
4-17-52	Strong ammonia odor at toilet - spray - very little odor near tank.
4-18-52	Some foam - plastic hose used to replace copper tubing. Strong odor at toilet - spray at toilet.
4-21-52	Condition of toilet, dark gelatinous growth - strong sickly odor - liquid dark brown with green tint, foaming. Some foam at drum, some odor close to drum.
4-21-52	Hose connection on pressure side of pump pulled loose. Experiment suspended.

Specifically, the experiment was designed to determine if the system installed could stabilize and store human excreta over a long period of time in a liquid media being constantly recirculated through the toilet, without creating a nuisance. In this respect the system proved to be both a partial success and a failure.

In spite of a slight odor and foaming, the receiving tank was relatively inoffensive considering the use to which it was being put. However, from the standpoint of appearance and odor, the toilet was unsatisfactory. A nauseous odor carrying a trace of ammonia was present throughout the last week of the experiment. During the night an unsightly brown gelatinous deposit formed at the water line of the toilet. Although this deposit was removed each morning, it would start to form again before the end of the work day. After the first day in use foaming, which was aggravated by the roughness of the deposit that formed on the bowl, produced a mistlike spray at the toilet. This continual spray produced droplets, some of which dried on the seat making the toilet unsightly and unpleasant for use.

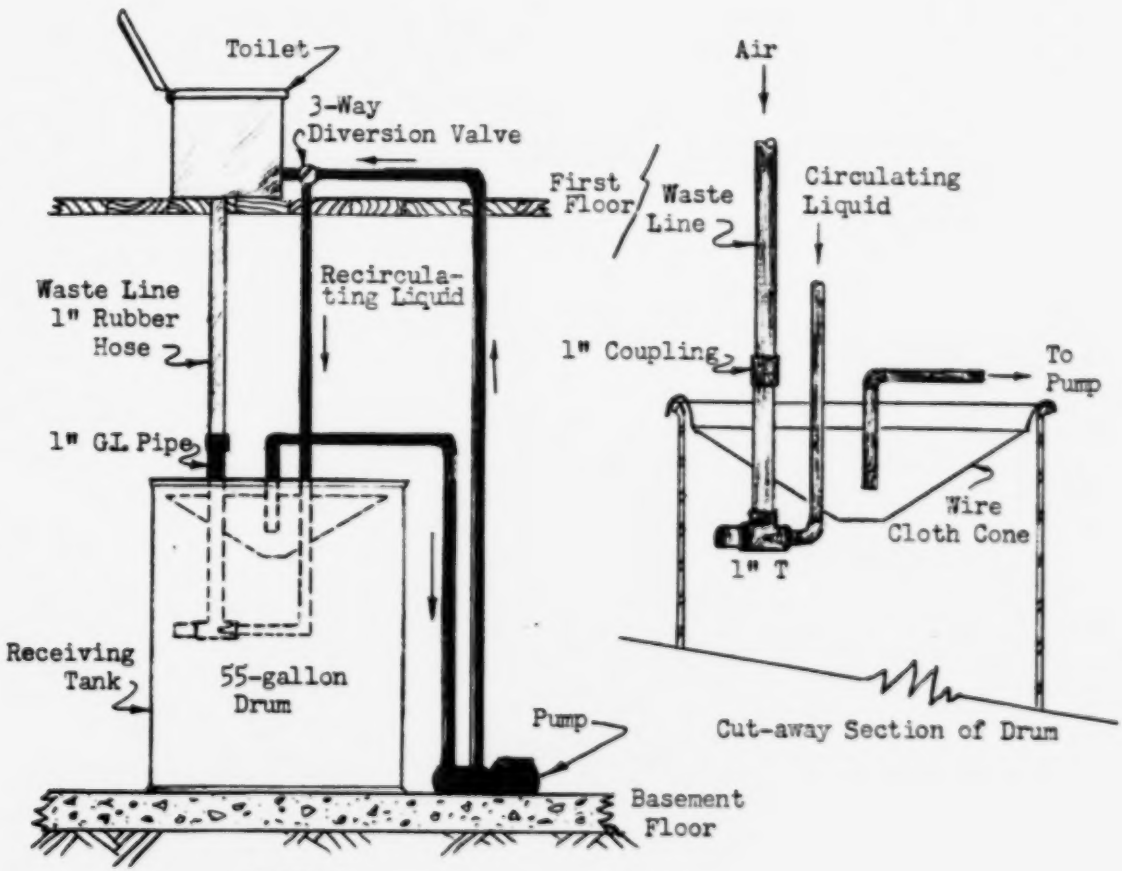
Originally it was planned that the trial might be conducted over an extended period of time, and that solids and B.O.D. determinations were to be made at weekly intervals. However, because of the nuisance which was created at the toilet, the experiment was about to be concluded at the end of the second week, when an accident occurred, and brought it to an abrupt end. On the evening of April 21, 1952 a hose connection pulled loose, and a large part of the tank contents were lost before the break was discovered.

Therefore, the data on solids build-up and B.O.D. are scanty. From the two observations obtained it appears that solids will accumulate at a substantial rate. During this two-week period the toilet was used 156 times, and 5,548 ppm total solids accumulated in the mixed liquor. This amounts to approximately 5.9 grams per toilet use. It should be noted here that these figures on solids are based on a sample siphoned from mid-depth in the drum. The manner in which the trial ended made it impossible to secure a sample from the mixed tank contents. Neither has any correction been made for ammonium salts which are unstable at the temperature of drying, 103°C, and must be a factor in this case.

Trial B

Continuous Recirculation, Diverted Through Toilet for Flushes Only

As most of the aesthetic objections which arose in the Trial A arrangement could be traced directly to the constant recirculation of liquid through the toilet, the system was revised and, another test was initiated on May 1, 1952. The equipment was set up as illustrated. A three-way valve arrangement at the toilet diverted the recirculating liquid so that fluid passed through the toilet only when the valve was operated for flushes. Air was supplied to the system through an aspirator arrangement as shown. When the toilet was not in use, the waste line served as an air intake for the aspirator.



TRIAL B

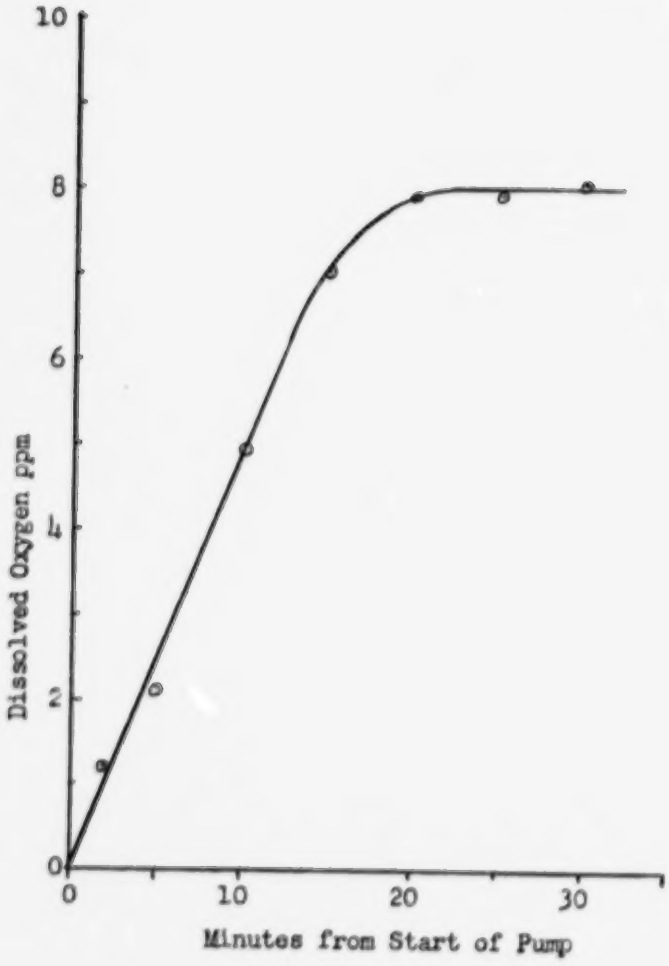


Figure 2

Second Trial
Reoxygenation of Tap-Water
51.75 gallons H_2O at 27°C

REOXYGENATION OF TAP-WATER

D.O. Content	D.O. Deficiency*	Minutes to Supply 1 ppm	Grams Per Day
7 ppm	1 ppm	7.0	40.3
6 ppm	2 ppm	2.5	113
5 ppm	3 ppm	2.0	141
0	8 ppm	2.0	141

*Oxygen saturation value minus oxygen content

Using the same method as described for the first part of the experiment, the capacity of the unit to reoxygenate tap water was determined. Results of this determination are given on Figure 2. A constant rate of reoxygenation at oxygen levels greater than two ppm below saturation is not typical. As the dissolved oxygen deficit increases the rate of reoxygenation should increase. The fact that this unit registered a constant rate over a large range of deficiencies might indicate that it can supply dissolved oxygen at a maximum rate of 141 grams per day.

After the reoxygenation rate had been determined, the drum was drained, rinsed clean and refilled with tap water. The system was put into use at 2:00 P.M. on May 1, 1952. As in the earlier trial, a daily record was kept of usage and oxygen dissolved in the receiving tank. These records are tabulated in Table No. IV.

Once each week the tank liquor was analyzed for solids and B.O.D. With the exception of those taken on May 26, samples were siphoned from the drum at mid-depth. At the conclusion of the study on May 26, samples were taken after the contents of the drum had been thoroughly stirred. Results of these weekly determinations are listed in Table V.

TABLE V

Weekly Results

Sampling Date	Solids ppm				5-day B.O.D. ppm
	T.S.	T.V.S.	S.S.	S.V.S.	
May 8, 1952	2338	1831	1438	489	215
May 15, 1952	3588	2422	1084	882	252
May 19, 1952	--	--	--	--	122
May 22, 1952	5186	3613	1734	1426	1048
May 26, 1952	12705	8880	--	--	1406

TABLE IV

Daily Records

Date	Feces	Urine	Toilet Paper	Dissolved Oxygen ppm Morning	Dissolved Oxygen ppm Night	Temp. °C	pH
May 1, 1952	2	3	Grams	8.2	7.3	15.8	8.5
May 2, 1952	7	9		5.6	4.0	26.0	
Weekly Total	9	12	57				
May 5, 1952	7	11		3.6	0.3	28.0	
May 6, 1952	2	5			2.5	29.0	
May 7, 1952	3	4		1.2	1.3	28.0	
May 8, 1952	4	7		2.2	1.2	27.0	9.0
May 9, 1952	6	11		.9	.6	28.5	
May 10, 1952	1	3					
May 11, 1952	1	0					
Weekly Total	24	41	93.5				
May 12, 1952	6	13		1.9	1.3	26.8	
May 13, 1952	3	8		1.2	1.3	28.2	
May 14, 1952	7	8		.8	.8	29.8	8.9
May 15, 1952	6	10		0	.7	29.0	9.0
May 16, 1952	7	12		0	0	30.0	8.7
Weekly Total	29	51	167.5				
May 19, 1952	8	12		0	0	28.8	8.7
May 20, 1952	4	12		0	0	29.8	8.7
May 21, 1952	4	11		0	0	30.0	8.7
May 22, 1952	4	10		0	0	30.0	8.7
May 23, 1952	6	6		0	0	30.0	8.7
Weekly Total	26	51	121.0				
May 26, 1952	1	3	13.0	0	0	28.0	8.7
Total	89	158	452.0				

On May 28, after the toilet had been out of operation for approximately three days, the content of the drum was thoroughly mixed and sampled. The ammonia nitrogen, oxygen consumed and B.O.D. of the sample was found to be:

Ammonia Nitrogen	1,630 ppm
Oxygen consumed	10,700 ppm
B.O.D. (5 days)	1,740 ppm

As in the previous experiment, a daily record was kept of comments concerning the appearance of the unit, and any nuisances which were observed.

The method of recirculation used in the second trial was superior aesthetically to that used in the first trial. However, some unsatisfactory characteristics persisted. At the drum there was continuous foaming which formed an unsightly brown crust around pipes and the lip of the drum. Foaming also produced a fine spray that dried on the wall adjacent to the drum. This condition was probably aggravated by the high liquid level in the tank. A musty odor, which was faint at the start of the trial, became progressively more pronounced and reached a serious stage by the end of the third full week. This odor was especially noticeable in the morning when the laboratory was first opened. However, once the room was aired, it was necessary to stand near the receiving tank before the odor could be detected. The wire cone in the receiving tank clogged early in the trial. When it was removed, it was found that the screen was covered with a solid coat of fecal matter, matted together with what appeared to be toilet paper fibers. No effluent was discharged from the system and five gallons of makeup water were added during the trial.

In contrast with the first trial, it was some time before the nuisances which developed at the toilet made it unacceptble. An ammonia odor which grew stronger as the study progressed, was liberated at each toilet flush. Although there was no noticeable spraying or splashing, the toilet bowl was

usually inadequately flushed and required frequent cleaning. It was easily cleaned by brushing without the aid of detergents or other chemicals. After the first few days the flushing liquid took on a light brown color that persisted during the life of the test.

The nuisances which were slight at first became more noticeable with time and usage. By May 23, because of the odor of the drum and its unsightly appearance coupled with the strong ammonia tainted odor liberated at each toilet flush, the unit had become objectionable.

As the investigation had reached a logical end point by May 26, 1952, it was concluded. The contents of the drum were not emptied immediately, but were allowed to stand undisturbed. A highly repugnant odor developed which became more and more intense. By the morning of May 28 this odor had become intolerable and the contents of the drum were disposed of.

Solids accumulated in the tank at a fairly rapid rate. Computations based on the samples taken May 26 show that approximately 10 grams of solids were accumulated for each toilet use. This figure, however, is based only on the total solids as determined by evaporation and should be corrected for ammonium salts which decompose at temperatures lower than 103°C. The ammonia nitrogen determination made on a sample taken on May 28 showed 1,630 ppm as NH_3. Considering the hydrolysis of urea, $CO(NH_2)_2 + 2H_2O \rightarrow (NH_4)_2\ CO_3$, and neglecting the production of CO_2 and the possibility of anaerobic digestion with the attendant production of volatile acids, it might be assumed that the ammonium ions were largely combined with carbonate ions. The high pH lends credence to this assumption. One thousand six hundred and thirty ppm of NH_3 is equivalent to 4,603 ppm of $(NH_4)_2\ CO_3$ which would decompose at a temperature lower than that of drying, 103°C. If the total solids as determined are corrected by this amount, the drum contained approximately 17,000 ppm total solids. This represents a total dry weight

computed. The rate of reoxygenation was taken as that which would occur in tap-water at the same dissolved oxygen level as the tank contents. These rates were taken from Figure 2.

When the average hypothetical weight of oxygen supplied per fecal use on a cumulative basis was compared with the dissolved oxygen content of the liquor, an interesting correlation was established. After the unit had been in use for several days and with the exception of one case, when the dissolved oxygen supplied per fecal use fell below 40 grams, no dissolved oxygen could be detected in the drum. The one exception was on Monday morning, May 19. At that time the tank contained 1.6 ppm dissolved oxygen, and 38.9 grams of oxygen per fecal use had been dissolved. There was a measureable amount of dissolved oxygen present in all cases where an amount of oxygen greater than 40 grams per fecal use had been absorbed.

The same computations were made for the first trial, and the same relationship was found to exist. When the oxygen supplied was greater than 40 grams per fecal use the tank contained dissolved oxygen. After the first three days, when less than 40 grams of oxygen per fecal use were supplied, no dissolved oxygen was found in the tank.

The significance of 40 grams lies in the relationship between the ability of a unit to reaerate tap water and its ability to maintain aerobic conditions under an imposed loading as measured by fecal uses. Even though the exact quantity of oxygen required to supply the ultimate demand per fecal use cannot be obtained from this information, the data do indicate that to maintain aerobic conditions an aerating system must be able to supply at least 40 grams of oxygen to tap water for each intended fecal use. Thus, if a system were to carry a loading of eight fecal uses per day, it should have sufficient capacity to supply tap water with 320 grams of oxygen per day.

of 3.33 kilograms or 13.5 grams per toilet use.

Neither casual nor microscopic examination of liquor from the tank disclosed any forms or organization of the material that resembled a typical activated sludge. A murky tan color developed early in the trial. The color which had become quite intense by the end of the experiment persisted even after coagulants had been applied. Four beakers of the liquid were allowed to stand in the laboratory for two weeks. In that period there was no clarification or apparent change in the character of the material. When the drum was emptied it was noted that the settleable solids had the characteristics of undigested fecal matter.

Referring to Table IV it is seen that during the first two weeks of the trial a residual of dissolved oxygen was maintained in the receiving tank. On Friday, the 16th, the dissolved oxygen content dropped to zero. Oxygen was again present by the following Monday morning, but by that afternoon, the dissolved oxygen content had dropped to zero and did not recover for the remainder of the trial. In spite of the absence of dissolved oxygen in the tank contents during the last eleven days of the experiment, no intolerable nuisance developed as long as the pump was running and air was being supplied. As noted above, when the pump was turned off a foul odor quickly developed.

Kessener and Ribbius[1] have demonstrated that the reaeration of settled sewage does not produce the same regular oxygen absorption curve as that obtained with clean water. Dissolved oxygen in sewage increased more slowly, became constant, and then decreased. However, it seems logical to assume that, even though the behavior is different, the ability of a system to aerate sewage is probably related to its ability to reaerate tap-water.

Using the rate at which this system would reaerate tap-water, a hypothetical quantity of dissolved oxygen supplied for each fecal use was

Summary and Conclusions

A system which had been proposed for the treatment of toilet wastes, and a modification of that system, were tested. The objective of the tests was to determine if the system evaluated could stabilize and store human excreta over a long period of time in a liquid media being constantly recirculated without creating a nuisance.

The unit tested consisted of three functional parts: a grinder type toilet, a receiving tank, and a pump. Ground waste flowed from the toilet to the receiving tank. During Trial A the pump continuously recirculated the tank contents through the toilet; while in trial B the constantly recirculating liquor was diverted through the toilet for flushes only. In the process of recirculation, air was introduced, and the recirculating liquid was used to accomplish toilet flushes. No effluent was discharged from the system.

A conventional toilet in the men's room was replaced with a grinder-type toilet. A one-inch rubber hose was used to convey the finely ground waste from the toilet to an open 55-gallon drum on the next floor below.

Before being put into actual service the rates at which the system used in each trial would reaerate tap-water, which had been chemically freed of dissolved oxygen, were determined.

During both trials a record was made of the number and types of uses, the toilet paper used, and comments concerning nuisances which developed. Samples were taken at scheduled intervals to determine solids build-up, B.O.D., and D.O. of the tank contents.

Conclusions

Trial A

(1) The arrangement proposed for the treatment of toilet waste in a closed system in which the liquor being treated was constantly recirculated through the toilet bowl proved to be unsatisfactory. A strong odor, a gelatinous deposit, and excessive spray developed at the toilet.

Trial B

(1) Experimental operation of a second proposed arrangement in which air was supplied through an aspirator device, and liquor passed through the toilet for flushes only was conducted over a period of approximately 26 days.

(2) During this trial, nuisances which were slight at first became more noticeable with time and usage. By the end of the third week the unsightly appearance and odor at the receiving tank coupled with the strong ammonia tainted odor emitted at the toilet with each flush made the unit objectionable.

(3) When the pump was turned off, thus stopping the supply of air, a highly offensive odor developed at the receiving tank. By the morning of the third day, after aeration was discontinued, this odor became intolerable and the contents of the drum were discarded.

(4) Total solids corrected for the loss of ammonium nitrogen assumed to be in the form of $(NH_4)_2\ CO_3$ accumulated at the rate of 13.5 grams per toilet use.

(5) A comparison of five-day B.O.D. with corresponding volatile solids determinations presents an unusual picture. Furthermore, for the one determination made, the ratio of oxygen consumed to five-day B.O.D. seems entirely out of line. These results suggest that normal aerobic oxidation was not taking place in this material.

(6) A measurable quantity of dissolved oxygen was maintained in the tank liquor as long as the computed hypothetical amount of dissolved oxygen supplied per fecal use exceeded 40 grams.

(7) Microscopic examination of the mixed liquor showed no typical activated sludge formations. At the time of emptying, solids which had settled in the drum had the physical appearance of undigested fecal matter.

References:

(1) Kessener and Ribbius. "Comparison of Aeration Systems for the Activated Sludge Process." Sewage Works Journal. V 6 (423) 1934.

(2) Bloodgood, Don E. "A New System for Home Sewage Disposal." Presented at Engineering Section, A.P.H.A., October 23, 1952.